

WHAT IS CLAIMED IS:

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1. A tilt sensor for determining information related to a tilt of an object to a reference plane, comprising:

10 a diffraction element disposed at a position on an optical path of a light beam from the object, the position determined in accordance with a positional relation with the object, wherein the diffraction element diffracts diffraction light at a diffraction efficiency depending on an incident angle
15 of the light beam; and

a photo detector that receives the diffraction light diffracted by said diffraction element and outputs an photoelectric signal.

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2. The tilt sensor as claimed in claim 1, wherein an order of the diffraction light received by
25 said photo detector is that of a diffracted light of

a greatest intensity.

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3. The tilt sensor as claimed in claim 1,
wherein said diffraction element is set so that the
relation between the intensity of the diffraction
light and the incident angle is substantially linear
10 an a predetermined range of the incident angle.

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4. The tilt sensor as claimed in claim 1,
further comprising a differential signal generator,
wherein

said photo detector receives 0 order
diffraction light from said diffraction element, and

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said differential signal generator
generates a differential signal between the
photoelectric signal of the diffraction light and the
0 order diffraction light.

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5. The tilt sensor as claimed in claim 1,
further comprising a differential signal generator,

5 wherein

 said photo detector receives +1st order
diffraction light and -1st order diffraction light
from said diffraction element, and

 said differential signal generator
10 generates a differential signal between a
photoelectric signal of the +1st order diffraction
light and a photoelectric signal of the -1st order
diffraction light.

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6. The tilt sensor as claimed in claim 1,
wherein

20 said diffraction element comprises a first
region in which a grooved grating of a first groove
direction is formed and a second region in which a
grooved grating of a second groove direction is
formed; and

25 said photo detector comprises a first photo

detecting unit that receives the diffraction light
from the first region and a second photo detecting
unit that receives the diffraction light from the
second region.

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7. The tilt sensor as claimed in claim 6,
10 wherein an order of the diffraction light received by
the first photo detecting unit and an order of the
diffraction light received by the second photo
detecting unit are those of diffracted light of the
greatest intensity.

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8. The tilt sensor as claimed in claim 6,
20 wherein

said diffraction element is set so that
the relation between the intensity of the
diffracted light received by the first photo
detecting unit and the incident angle of the
25 diffracted light beam to the first region is

substantially linear in a first range, and

the relation between the intensity of the
diffracted light received by the second photo
detecting unit and the incident angle of the
5 diffracted light beam to the second region is
substantially linear in a second range.

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9. The tilt sensor as claimed in claim 6,
further comprising a first differential signal
generator,

wherein

15 said photo detector includes a third photo
detecting unit that receives 0 order diffraction
light from said diffraction element, and

said first differential signal generator
generates a differential signal between a
20 photoelectric signal from the first photo detecting
unit and a photoelectric signal from the third photo
detecting unit.

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10. The tilt sensor as claimed in claim 9,
further comprising a second differential signal
generator,

5 wherein

 said second differential signal generator
generates a differential signal between a
photoelectric signal from the second photo detecting
unit and a photoelectric signal from the third photo
10 detecting unit.

15 11. The tilt sensor as claimed in claim 6,
further comprising a first differential signal
generator,

 wherein

 the first photo detecting unit receives
20 +1st order diffraction light and -1st order
diffraction light from the first region, and

 said first differential signal generator
generates a differential signal between a
photoelectric signal of the +1st order diffraction
25 light and a photoelectric signal of the -1st order

diffraction light output by the first photo detecting unit.

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12. The tilt sensor as claimed in claim 11, further comprising a second differential signal generator,

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wherein

the second photo detecting unit receives +1st order diffraction light and -1st order diffraction light from the second region, and

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said second differential signal generator generates a differential signal between a photoelectric signal of the +1st order diffraction light and a photoelectric signal of the -1st order diffraction light output by the second photo detecting unit.

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13. The tilt sensor as claimed in claim 1, wherein a cross section of said diffraction element

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is serriform.

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14. The tilt sensor as claimed in claim 1,
wherein the light beam from the object is a
reflective light reflected by the object.

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15. The tilt sensor as claimed in claim 14,
further comprising a light source that emits a light
15 beam to a direction forming an angle with the
reference plane,

wherein

said diffraction element is disposed on an
optical path of the reflective light reflected by the
20 object.

25

16. The tilt sensor as claimed in claim 15,

further comprising an optical element disposed on an optical path of a light beam traveling from said light source to the object, wherein said optical element makes the light beam emitted by said light source substantially parallel.

10 17. The tilt sensor as claimed in claim 15, further comprising a phase difference plate, wherein

 said diffraction element is a polarization diffraction element that diffracts the light beam in a different manner depending on a polarization state of the light beam, and

 said polarization difference plate rotates the directions of polarization in which the reflective light is polarized about by 90 degree to the directions of polarization in which the light beam emitted by said light source is polarized, the reflective light incoming to said polarization diffraction element.

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18. A tilt measurement apparatus for
determining a tilt angle of an object to a reference
5 plane, comprising:

the tilt sensor as claimed in claim 15; and
a tilt angle determination unit that
determines the tilt angle based on an output signal
from said tilt sensor.

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19. An optical pickup apparatus that
15 applies a light to a recording surface of a recording
medium and receives a reflective light from the
recording surface, comprising:

the tilt sensor as claimed in claim 15,
wherein the object is the recording medium;

20 a laser light source that emits a laser
light, the wavelength of which corresponds to the
recording medium;

an optical system including an object lens
for converging the laser light on the recording
25 surface, wherein said optical system guides the

reflective laser light reflected by the recording surface via the object lens to a receiving position; and

5 a photo detector disposed at the receiving position, wherein said photo detector receives the reflective light beam.

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20. An optical pickup apparatus that applied a light to a recording surface of a recording medium and receives a reflective light from the recording surface, comprising:

15 a laser light source that emits a laser light, the wavelength of which corresponds to the recording medium;

an optical system including an object lens for converging the laser light on the recording surface, wherein said optical system guides the reflective laser light reflected by the recording surface via the object lens to a receiving position;

20 a signal light detector that receives disposed at the receiving position, wherein said signal light detector receives the reflective light

25

beam;

a split optical element disposed on an optical path of a light beam emitted by said laser light source to the object lens, wherein said split
5 optical element splits a fraction of the laser light to the recording medium; and

the tilt sensor as claimed in claim 14, said diffraction element of which is disposed on an optical path of the laser light split by said split
10 optical element and reflected by the recording medium, wherein the object is the recording medium.

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21. An optical disk apparatus, comprising:
the optical pickup apparatus as claimed in
claim 19;

an adjusting unit that adjusts a shape of
20 light spot formed on the recording surface based on the output signal from said tilt sensor; and

a processing unit that at least reproduces information using the output signal from said optical pickup apparatus.

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22. An optical disk apparatus, comprising:
5 the optical pickup apparatus as claimed in
claim 20;

an adjusting unit that adjusts a shape of
light spot formed on the recording surface based on
the output signal from said tilt sensor; and

10 a processing unit that at least reproduces
information using the output signal from said optical
pickup apparatus.

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23. A tilt sensor for detecting information
related to a tilt of an object to a reference plane,
comprising:

20 a diffraction unit disposed at a position
on an optical path of a light beam via the object,
the position determined in accordance with a
positional relation with the reference plane, wherein
said diffraction unit diffracts the light beam in
25 first directions at a diffraction efficiency

determined by an incident angle of the light beam in
the first directions, and diffracts the light beam in
second directions at a diffraction efficiency
determined by an incident angle of the light beam in
5 the second directions; and

a photo detection unit that receives a
diffraction light from said diffraction unit, and
outputs a photo-electric signal.

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24. The tilt sensor as claimed in claim 23,
wherein said diffraction unit further comprises:

15 a first diffraction element that diffracts
the light beam in the first directions at the
diffraction efficiency determined by the incident
angle of the light beam in the first directions; and

a second diffraction element that diffracts
20 the light beam in the second directions at the
diffraction efficiency determined by the incident
angle of the light beam in the second directions.

25

25. The tilt sensor as claimed in claim 24,
wherein said first diffraction element and said
second diffraction element are laminated.

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26. The tilt sensor as claimed in claim 24,
10 wherein said first diffraction element satisfies

$$2 \leq 2\pi\lambda T_a / n_a d_a^2 < 10,$$

where λ denotes a wavelength of the light
beam, n_a denotes a refraction index of said first
diffraction element, T_a denotes depth of diffraction
15 grating formed on said first diffraction element, and
 d_a denotes pitch of the diffraction grating formed on
said first diffraction element.

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27. The tilt sensor as claimed in claim 24,
wherein said second diffraction element satisfies

$$2 \leq 2\pi\lambda T_b / n_b d_b^2 < 10,$$

25 where λ denotes a wavelength of the light

beam, n_b denotes a refraction index of said first
diffraction element, T_b denotes depth of diffraction
grating formed on said second diffraction element,
and d_b denotes pitch of the diffraction grating formed
5 on said second diffraction element.

10 28. The tilt sensor as claimed in claim 23,
wherein a first diffraction grating and a second
diffraction grating are formed on a same surface of
said diffraction unit, wherein the first diffraction
grating diffracts the light beam in the first
15 directions at the diffraction efficiency determined
by the incident angle of the light beam in the first
directions, and the second diffraction grating
diffracts the light beam in the second directions at
the diffraction efficiency determined by the incident
20 angle of the light beam in the second directions.

25 29. The tilt sensor as claimed in claim 28,

wherein the first diffraction grating satisfies

$$2 \leq 2\pi\lambda T_a/n_a d_a^2 < 10,$$

where λ denotes a wavelength of the light beam, n_a denotes a refraction index of the first
5 diffraction grating, T_a denotes depth of the first diffraction grating, and d_a denotes pitch of the first diffraction grating.

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30. The tilt sensor as claimed in claim 28,
wherein the second diffraction grating satisfies

$$2 \leq 2\pi\lambda T_b/n_b d_b^2 < 10,$$

15 where λ denotes a wavelength of the light beam, n_b denotes a refraction index of the second diffraction grating, T_b denotes depth of the second diffraction grating, and d_b denotes pitch of the second diffraction grating.

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31. The tilt sensor as claimed in claim 23,
25 wherein the first directions and the second

directions are substantially perpendicular to each other.

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32. The tilt sensor as claimed in claim 23, further comprising:

a polarization unit disposed on the optical
10 path between said diffraction unit and said photo
detection unit, wherein said polarization unit
polarizes the diffraction light from said diffraction
unit,

wherein

15 said photo detection unit receives a
diffraction light polarized by said polarization unit.

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33. The tilt sensor as claimed in claim 23, further comprising:

a convergence lens disposed on the optical
path between said diffraction unit and said photo
25 detection unit, wherein said convergence lens

converges the diffraction light from said diffraction unit,

wherein

said photo detection unit receives a
5 diffraction light converged by said convergence lens.

10 34. The tilt sensor as claimed in claim 23,
further comprising:

a light source that emits the light beam;

and

an optical unit disposed on the optical
15 path between said light source and the object,
wherein said optical unit makes the light beam
emitted by said light source substantially parallel.

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35. The tilt sensor as claimed in claim 34,
wherein

said optical unit and said diffraction unit
25 are combined as a single unit.

5 36. The tilt sensor as claimed in claim 34,
 wherein
 said light source and said photo detector
are built in a package.

10

 37. The tilt sensor as claimed in claim 36,
 wherein
15 the light beam emitted by said light source
and the light beam via the object are polarized in
different directions, and
 said diffraction unit diffracts the light
beam via the object at a higher diffraction
20 efficiency than a diffraction efficiency at which
said diffraction unit diffracts the light beam
emitted by said light source.

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38. A tilt sensor for detecting information related to a tilt of a first object to a reference plane, and information related to a tilt of a second
5 object to the reference plane, comprising:

a first diffraction unit disposed at a position on an optical path of a first light beam via the first object, the position determined in accordance with a positional relation with the
10 reference plane, wherein said first diffraction unit diffracts the first light beam in first directions at a diffraction efficiency determined by an incident angle of the first light beam in the first directions, and diffracts the first light beam in second
15 directions at a diffraction efficiency determined by an incident angle of the first light beam in the second directions;

a second diffraction unit disposed at a position on an optical path of the second light beam
20 via the second object, the position determined in accordance with a positional relation with the reference plane, wherein said second diffraction unit diffracts the second light beam in first directions at a diffraction efficiency determined by an incident
25 angle of the second light beam in the first

directions, and diffracts the second light beam in second directions at a diffraction efficiency determined by an incident angle of the second light beam in the second directions; and

5 a photo detection unit that receives a diffraction light from said first diffraction unit and a diffraction light from said second diffraction unit, and outputs a photo-electric signal.

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39. The tilt sensor as claimed in claim 38, wherein

15 said first diffraction unit further comprises:

 a first light beam first diffraction element that diffracts the first light beam in the first directions at the diffraction efficiency
20 determined by the incident angle of the first light beam in the first directions; and

 a first light beam second diffraction element that diffracts the first light beam in the second directions at the diffraction efficiency
25 determined by the incident angle of the first light

beam in the second directions.

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40. The tilt sensor as claimed in claim 39,
wherein

said first light beam first diffraction
unit and said first light beam second diffraction
10 unit are laminated.

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41. The tilt sensor as claimed in claim 38,
wherein

a first light beam first diffraction
grating and a first light beam second diffraction
grating are formed on a same surface of said
20 diffraction unit, wherein the first light beam first
diffraction grating diffracts the first light beam in
the first directions at the diffraction efficiency
determined by the incident angle of the first light
beam in the first directions, and the first light
25 beam second diffraction grating diffracts the first

light beam in the second directions at the
diffraction efficiency determined by the incident
angle of the first light beam in the second
directions.

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42. The tilt sensor as claimed in claim 38,
10 wherein
said second diffraction unit further
comprises:

a second light beam first diffraction
element that diffracts the second light beam in the
15 first directions at the diffraction efficiency
determined by the incident angle of the second light
beam in the first directions; and

a second light beam second diffraction
element that diffracts the second light beam in the
20 second directions at the diffraction efficiency
determined by the incident angle of the second light
beam in the second directions.

25

43. The tilt sensor as claimed in claim 42,
wherein

5 said second light beam first diffraction
element and said second light beam second diffraction
element are laminated.

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44. The tilt sensor as claimed in claim 38,
wherein

a second light beam first diffraction
grating and a second light beam second diffraction
15 grating are formed on a same surface of said second
diffraction unit, wherein the second light beam first
diffraction grating diffracts the second light beam
in the first directions at the diffraction efficiency
determined by the incident angle of the second light
20 beam in the first directions, and the second light
beam second diffraction grating diffracts the second
light beam in the second directions at the
diffraction efficiency determined by the incident
angle of the second light beam in the second
25 directions.

5 45. The tilt sensor as claimed in claim 38,
 wherein

 the first light beam and the second light
beam are polarized in different directions;

 said first diffraction unit diffracts the
10 first light beam at a higher diffraction efficiency
than a diffraction efficiency at which said first
diffraction unit diffracts the second light beam; and

 said second diffraction unit diffracts the
second light beam at a higher diffraction efficiency
15 than a diffraction efficiency at which said second
diffraction unit diffracts the first light beam.

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 46. The tilt sensor as claimed in claim 38,
 wherein

 the first directions and the second
directions are substantially perpendicular to each
25 other.

5 47. The tilt sensor as claimed in claim 38,
further comprising:

 a polarization unit that polarizes the
diffraction light,

 wherein

10 said photo detection unit receives a
diffraction light polarized by said polarization unit.

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 48. The tilt sensor as claimed in claim 38,
further comprising:

 a convergence lens that converges the
diffraction light,

20 wherein

 said photo detection unit receives a
diffraction light converged by said convergence lens.

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49. An optical pickup apparatus,
comprising:

5 a signal light source that emits a signal
light beam, a wavelength of which corresponds to an
optical disk;

an optical system that guides the signal
light beam to the optical disk;

10 a photo detector that detects a reflective
light beam reflected by the optical disk, wherein the
reflective light beam is guided by said optical
system;

a sensor light source that emits a sensor
light beam to the optical disk; and

15 the tilt sensor as claimed in claim 23,
wherein the tilt sensor is disposed on an optical
path of the sensor light beam reflected by the
optical disk, and the optical disk is the object.

20

50. An optical pickup apparatus,
comprising:

25 a signal light source that emits a signal

light beam, a wavelength of which corresponds to an optical disk;

an optical system that guides the signal light beam to the optical disk;

5 a photo detector that detects a reflective light beam reflected by the optical disk, wherein the reflective light beam is guided by said optical system; and

the tilt sensor as claimed in claim 34,
10 wherein the tilt sensor is disposed on an optical path of the sensor light beam reflected by the optical disk, and the optical disk is the object.

15

51. An optical pickup apparatus,
comprising:

a signal light source that emits a signal
20 light beam, a wavelength of which corresponds to an optical disk;

an optical system that guides the signal light beam to the optical disk, said optical system including an object lens that converges the signal
25 light beam on a recording surface of the optical

disk;

a photo detector that detects a reflective light beam reflected by the optical disk, wherein the reflective light beam is guided by said optical

5 system;

a sensor light source that emits a sensor light beam to the optical disk;

a splitter unit disposed on an optical path of the sensor light beam, wherein said splitter unit
10 splits the sensor light beam; and

the tilt sensor as claimed in claim 38, wherein the first light beam is the sensor light beam reflected by said splitting unit, and the second light beam is the sensor light beam that transmits
15 through said splitting unit and is reflected by the optical disk.

20

52. An optical disk apparatus that can at least reproduce data written on a recording surface of an optical disk, comprising:

the optical pickup apparatus as claimed in
25 claim 49;

an adjusting unit that adjusts wave front
aberration of a light spot formed on the recording
surface of the optical disk based on an output signal
from the tilt sensor of the optical pickup apparatus;
5 and

a processing unit that at least reproduces
data using an output signal from said photo detector.

10

53. A tilt sensor for detecting information
related to a tilt of an object to a reference plane,
comprising:

15 a diffraction element having a diffraction
grating disposed at a position on an optical path of
a light beam from the object, the position determined
in accordance with a positional relation with the
object, wherein the diffraction grating diffracts the
20 light beam at a diffraction efficiency depending on
an incident angle of the light beam;

a photo detector that receives a $\pm 1^{\text{st}}$ order
diffraction lights diffracted by said diffraction
element and outputs an photoelectric signal; and

25 a differential signal generation unit that

generates a differential signal between the +1st order diffraction signal and -1st order diffraction signal,

wherein the tilt sensor is set to detect incident angle within a detectible range between $\pm\theta$, θ being Bragg's angle,

$$\sin\theta = \frac{\lambda}{2\Lambda}$$

where λ denotes a wavelength of the light beam, and Λ denotes a pitch of the diffraction grating.

10

54. The tilt sensor as claimed in claim 53, wherein the diffraction grating satisfies:

$$\frac{n\Lambda^2}{\pi\lambda} \leq d \leq 4.5 \times \frac{n\Lambda^2}{\pi\lambda}$$

where d denotes depth of the diffraction grating, n denotes an average of a refraction index n₀ of material forming the diffraction grating and n₁ of material filling a ditch of the diffraction grating.

20

5 55. The tilt sensor as claimed in claim 53,
wherein
the diffraction grating satisfies:

$$\frac{\lambda}{4d} \leq \Delta n \leq \frac{\lambda}{d}$$

10 where Δn denotes a difference between a
refraction index n_0 of material forming the
diffraction grating and n_1 of material filling a
ditch of the diffraction grating.

15

56. The tilt sensor as claimed in claim 53,
wherein
said diffraction element has a first
diffraction grating of first grating directions and a
20 second diffraction grating of second grating
directions different from the first grating
directions.

57. The tilt sensor as claimed in claim 56,
wherein

5 the first diffraction grating and the
second diffraction grating are substantially
perpendicular to each other.

10

58. The tilt sensor as claimed in claim 56,
wherein

 the first diffraction grating and the
15 second diffraction grating are formed on a single
substrate.

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59. The tilt sensor as claimed in claim 58,
wherein the first diffraction grating and

the second diffraction grating are formed on the same
surface of the substrate.

25

60. The tilt sensor as claimed in claim 53,
5 further comprising:

a $1/4$ wavelength plate disposed between
said diffraction element and the object,

wherein

said diffraction element is polarizable,
10 the diffraction efficiency of which depends on a
polarization of the incident light beam.

15

61. A tilt sensing apparatus, comprising:
the tilt sensor as claimed in claim 53; and
a tilt angle measuring unit that measures
the tilt angle of the object to the reference plane
20 based on an output signal from the tilt sensor.

25

62. An optical pickup apparatus that at

lease reproduce information in a recording medium,
comprising:

the tilt sensor as claimed in claim 53;
a light source that emits a light beam of a
5 wavelength corresponding to the recording medium;
an object lens that converges the light
beam on a recording surface of the recording medium;
an optical system that guides the light
beam to the recording surface and guides a reflective
10 light beam reflected by the recording surface to a
receiving position; and
a photo detector disposed at the receiving
position that receives the reflective light beam.

15

63. An optical disk driving apparatus,
comprising:

20 the optical pickup apparatus as claimed in
claim 62;

an adjusting unit that adjusts a shape of a
light spot formed on the recording surface of the
recording medium based on an output signal from the
25 tilt sensor;

an information processing unit that at least reproduces information by applying the light beam to the recording surface of the recording medium.